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Bendix Corporation 1984 Model Side-Scanning Sonar Counter Experiments in the Kenai River, 1986

by
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State of Alaska Steve Cowper, Governor

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ABSTRACT

Counting capabilities of the Bendix Corporation 1981 and 1984 model side-scanning sonar counters were compared in simultaneous testing on the north bank of the Kenai River in July, 1986. The 1984 counter offered several features thought to be advantageous for more accurately enumerating upstream migrating salmon that were not found on its predecessor. These features included variable hit criteria and additional transmit power. The new system was also designed for use without the tubular aluminum substrate used with previous models. Forty hours of data were collected for analysis. The total count recorded by the 1984 counter exceeded that of the 1981 counter by 4.2%. Further analysis of the data indicated that the differences between paired counts were not a function of timing of sampling or density of targets. There were differences in distribution of targets from shore between the two counters. These differences were attributed to the substrate needed for the 1981 model and this model's lack of the variable hit criteria feature.

KEY WORDS: Pacific salmon escapements, hydroacoustic enumeration, migratory behavior, Upper Cook Inlet

INTRODUCTION

The Kenai River drainage encompasses approximately 5200 km^2 of the western Kenai Peninsula, Alaska (Figure 1). Four species of Pacific salmon (*Oncorhynchus*) spawn in the river or tributary lakes and streams, and the drainage is considered the major producer of sockeye salmon (*O. nerka*) in Cook Inlet. Two runs of sockeye salmon occur in the Kenai River. An early run enters the river from late May through mid-June bound primarily for the clearwater tributaries of Upper Russian Lake (Figure 2). The late run enters the river from late June through mid-August and spawns throughout the system, primarily upstream of the outlet of Skilak Lake. Since 1964, only the late run of sockeye salmon has been commercially harvested.

Total returns of late run sockeye salmon to the system regularly exceed one million fish and were over three million fish in 1982 and 1983 (Tarbox and Waltemyer 1985). Escapements have averaged over 500,000 fish in the 5 years from 1982 through 1986.

Due to the glacial nature of the mainstem river, escapement enumeration within the drainage was limited to surveys of the clearwater spawning areas prior to 1968. These surveys proved inadequate because they provided no information concerning the proportion of the escapement which spawns in the glacially occluded waters of Kenai and Skilak Lakes and the mainstem Kenai River. Efforts to manage the commercial harvest of sockeye salmon were also hampered by the lack of daily and cumulative estimates of the total escapement into the river.

Hydroacoustic equipment designed for enumerating salmon in the mainstem river was installed at a location approximately 32 km upstream from the mouth of the river in 1968. Counting was accomplished with a Bendix Corporation multiple transducer sonar (MTS) system beginning in 1968 and continuing through the 1977 season. Although the MTS system appeared to provide a reasonably accurate estimate of the numbers of fish passing the site, it was extremely difficult and time consuming to install and retrieve. This was a significant problem because the unit's 30 separate transducers resulted in less than desired reliability and constant maintenance. When transducers ceased working or were blocked by debris, researchers had to extrapolate for the data lost during the repair process or manipulate the data gathered to account for lost or blocked transducers.

In 1975 a new side-scanning sonar counter developed by Bendix Corp. was tested on the Kenai River. This counter provided easy access to the transducer and an 18-m tubular aluminum substrate which was relatively easy to deploy, retrieve, and maintain (Figure 3). The side-scanning system, with minor modifications, has been used at the Kenai sonar site since the 1978 season. The system currently in use (1981 model) is basically a 1978 model with an upgraded printer. Results of hydroacoustic studies conducted from 1978 through 1985 are documented by Tarbox et al. (1981 and 1983), and King and Tarbox (1984, 1986 and 1987).

Several behavioral characteristics of sockeye salmon migrating past the Kenai River sonar counters influence the success of enumeration. The majority of the run is nocturnal, passing the site primarily between 1800 hours and 0400 hours (King and Tarbox 1986). During this period the migratory rate of sockeye salmon over the substrate, expressed as average upstream swimming speed,changes significantly. Shore orientation of migrating sockeye salmon can also change rapidly within a 24-h period. Fish typically cross the substrate within 5 m of the transducer during hours of darkness, and tend to move farther offshore during daylight. Consequently, the counters must be adjusted extensively to insure accurate escapement estimates.

These results elicited several questions. Was this sockeye salmon migrational behavior induced by the substrate? Did some proportion of the escapement move outside the substrate and miss being counted?

In addition, the processing criteria of the 1981 counter used to enumerate fish was questioned. Valid fish counts are enumerated by the processor when a preselected number of returning echoes per hydroacoustic target have been recorded. These 'hit criteria' are fixed for each linear sector, and fish may be overcounted or undercounted in any one sector depending on the accuracy of the hit criteria. If the criteria are incorrect and fish distribution across the substrate is variable, as suggested by previous years' data, then misleading fish distribution information could result.

Prior to the 1984 field season, Bendix Corp. was contracted by the Alaska Department of Fish and Game to develop a side-scanning sonar counter with long range counting capabilities which did not require an artificial substrate. The resultant 1984 experimental counter was tested at various sonar sites, including the Susitna River in northern Cook Inlet where previous studies indicated that the distribution of fish from shore exceeded the counting range of the 1978 counter. All river systems selected for testing were suspected of having counting problems associated with fish response to the artificial substrate. Results of tests conducted on the Susitna River are reported by King (1987).

By avoiding use of an artificial substrate on the Kenai River, researchers believed the 1984 counter results would document reduced variability in fish behavior and resultant time required to monitor the counting system. In addition, the space requirements were significantly reduced because cable mooring systems for the substrate were not needed. This reduced conflicts with adjacent land owners and river users. The ability to change the counting criteria for each sector should also result in increased counting and distribution accuracy.

Comparative testing of the 1984 model and 1981 model Bendix counters on the north bank of the Kenai River in 1986 included the following objectives:

1) compare sockeye salmon escapement estimates generated from data provided by the 1984 model and 1981 model counters;

2) compare the target distribution from shore as recorded by the two counters; and

3) evaluate fish behavior relative to the artificial substrate.

Because extensive data has been collected with the 1981 counter in previous years, comparison of the two counters was also expected to provide some measure of the degree of continuity in the data base which could be expected if the 1984 counter is used at this site in the future.

METHODS

The 1981 and 1984 model side-scanning sonar counters, as with all sonar systems, convert electrical energy into acoustical energy (sound waves) and provide information about underwater targets by measuring the returning echoes. Both counting units consist of an electronic sounder/processor, transducer and 12-V battery/solar panel power source. An oscilloscope is used to monitor and calibrate the system. The effective angles of detection are 2° and 4°. The transducer can be fired on the 2°, 4°, or alternate mode. In the alternate mode, the transducer fires one 2° pulse and accepts returning echoes from the inshore one-half of the counting range, followed by a 4° pulse with returning echoes accepted from the offshore one-half of the counting range. Pulse width of the transmitted sound wave is 100 μs and the frequency is 515 kHz and 500 kHz for the 1981 and 1984 models respectively. The pulse repetition rate and power (level of voltage applied to the transducer) are variable.

Both sounder/processors enumerate targets on the basis of returning echo strength (-38 decibel minimum) and number of echoes returned (minimum number of returning echoes from a target to meet the requirements for designation as a fish). The processor accumulates and prints the counts on tape, in 1-h intervals, for each of the linear sectors. Each sector is defined as one-twelfth (1981 model) or one-sixteenth (1984 model) of the total counting range.

The accuracy of both counters is assessed by comparing the ratio of visual (oscilloscope) counts to processor counts. This ratio can then be used to adjust the pulse repetition rate of the counter. In addition, the hit criteria (minimum number of returning echoes from a target to meet the requirements for designation as a fish) of the 1984 counter is adjustable within each linear sector.

The 1981 counter was designed for use in conjunction with an 18 m tubular aluminum substrate (Figure 3). The substrate provides an aiming surface, and forces fish into the ensonified area as they attempt to migrate upstream. The substrate rests on the stream bottom perpendicular to the channel axis. Aiming is accomplished by manually adjusting knobs attached to the transducer which control vertical and horizontal movement.

The 1984 model counter is fitted for two transducers which can be used individually or alternately fired for variable time periods. A single transducer was used for this study, and mounted on a tripod which allowed adjustment in the vertical and horizontal planes.

Additional differences between the counters includes a maximum power level (volts peak to peak) for the 1984 model of 240 V as contrasted to the maximum 60 V available for the 1981 model. The 1984 counter also includes a "rock inhibitor" function which eliminates counts from stationary targets that return a target strength greater than -38 decibels (dB). The blanking affect has a resolution of 0.4% of the total counting range for each stationary target encountered. Fish passing through the inhibited area are not counted, but are visible on the oscilloscope trace.

A more detailed description of the theory of operation of the Bendix Corp. side-scanning sonar counter (pre-1984 models), and description of the electronic equipment are presented in Gaudet (1983). Procedures for deployment and operation of the 1981 model counter are described in Bendix Corp. (1980). Similar information for the 1984 model is found in Bendix Corp. (1984).

The 1981 counter was deployed at a site on the north bank of the Kenai River originally established in 1978 (Figure 4). The counting range of the 1984 counter was established by initially setting the counting range to a maximum of 100 m, aiming along the bottom, and determining the point at which a characteristic bottom trace was no longer visible. This procedure was repeated at 5-m intervals along the north bank for approximately 50 m on either side of the deployed substrate to determine the most suitable location for deployment of the 1984 counter. The site selected was approximately 25 m upstream of the substrate.

Both transducers were deployed approximately 2 m from shore, and weirs which extended approximately 2 m offshore of the transducer face were installed immediately downstream of each transducer, which extended approximately 2 m offshore of the transducer face. Bottom profiles were generated for each of the counting sites using a Lorans X-15 chart recorder.

At the site selected for deployment of the 1984 counter, the maximum counting range was 24 m, or 26 m from shore when the 2-m distance from the shore to the transducer is included. This counting range provided an approximate linear distance of 1.5 m per counting sector, equal to that provided by the 1981 counter set to count at a counting range of 18 m.

In all hourly testing periods, both counters used the alternate counting mode (alternate 2° and 4° transmissions). Only those hours in which both counters were calibrated prior to and within the hour were selected for analysis.

Analysis of counter printouts included adjustments for counts in sectors which the attending biologist felt false counts had accumulated. Generally, these counts were the result of debris on the substrate (1981 counter), or slight shifts in the tripod which altered previously inhibited bottom counts (1984 counter). The procedure for adjusting these counts was to substitute an average count for suspect sector counts. The average count was calculated by dividing the total good counts in adjacent sector/hour blocks by the number of blocks. This adjustment was made for 12 of 480, 1981 counter sector/hour blocks and 10 of 640, 1984 counter sector/hour blocks used in subsequent analyses.

Hourly counts selected for analysis were subjected to Wilcoxon's signed rank test (Zar 1974) to test the hypothesis that the hourly fish counts were the same for both counters. A linear regression analysis was also performed to examine the relationship between hourly counts accumulated by each counter.

The distribution of hydroacoustic targets from shore was determined by totaling counts by sector for all hours combined. Sector totals were subjected to chi-square analysis to determine if reported distribution differences were significant.

RESULTS

Bottom profiles taken at the respective counter locations are presented in Figure 5. A slight drop of the bottom slope was measured at approximately 30 m from shore in front of the 1984 counter transducer. This point also marked the end of the counting range selected for the 1984 counter since targets migrating offshore of that point potentially passed below the beam. Bottom irregularities which activated the rock inhibitor in sector 10 (approximately 17 m from shore) were not visible on bottom profile echograms.

Sector counts by hour used for analysis are presented in Tables 1 and 2. Data were gathered from 21 July through 31 July when approximately 80% of the sockeye salmon escapement passed the sonar site. The 64,394 hydroacoustic targets recorded by the 1981 counter used in the analysis represented approximately 22% of the total targets enumerated by the north bank 1981 counter throughout the season. The majority of the data used for comparison of counters was collected from 2000 hours through 0100 hours, the period when nearly 50% of the total upstream migration occurred. This was also the period when upstream swimming speed was most variable. The 67,221 total counts recorded by the 1984 counter exceeded those of the 1981 counter by 4.2% for the 40 h of data gathered. Percent difference between paired hourly counts ranged from 0% to 169% (Table 3).

Paired counts for the hours documented in Tables 1 and 2 were subjected to the Wilcoxon paired sample test (Zar 1984). Results are presented in Table 3. Since the calculated T (299) and T′ (357) values were not less than the tabled T value (T,0.05(2),40 df = 264), the null hypothesis that the count from the 1984 counter was the same as the 1981 counter was accepted.

The hourly counts were also subjected to linear regression analysis to determine the degree of correlation between the two data sets (Table 4). The calculated correlation coefficient (r) of 0.94 exceeded the tabled value ($P < 0.05$, 38 df) of approximately .310, leading to rejection of the null hypothesis that there was no relationship between the two data sets. The calculated r^2 value (0.87) indicates that only 13% of the variability was not explained by the regression of the count from the 1984 counter to the count from the 1981 counter. Figure 6 graphically illustrates the test results, including the 95% confidence interval for expected values.

Figure 7 illustrates the counts by hour for successive hours beginning 1400 hours on 21 July. Results indicated that differences between paired data were not concentrated in any portion of the study period. Results were also examined to determine if percent difference between paired data were related to density of targets (Figure 8). It appears that differences in paired counts, expressed as percent of total count, were randomly distributed with respect to fish density.

The above tests and illustrations indicated that the total counts recorded by the 1984 counter were essentially the same as those recorded by the 1981 counter. Within the counting period, both counters accurately reflected changes in density of fish targets between successive hours, and despite the large variation within each data set, there was a high degree of correlation between the two data sets. Further analysis of the data indicated that the degree of difference between paired counts was not a function of timing of sampling, or density of targets.

Data were also examined relative to distribution of targets from shore and whether the distribution of enumerated targets accurately reflected the distribution of fish from shore. Fish migrating nearshore were pushed offshore 4 m by the weir directly downstream of each counter. These fish were, however, only partially hindered from entering the beam in Sector 1 and were unaffected in terms of passage within the remaining sectors. Assuming no other influences on upstream migration pattern and since both transducers were at approximately equal distances from shore and linear counting sectors were of approximately equal length, distribution should have been relatively equal past both counters.

Tables 1 and 2 and Figure 9 detail differences in distribution of targets from shore for the two counters. Nearly all (99.1%) of the targets recorded by the 1984 counter were within 6.8 m from shore. In contrast, 78.6% of the targets were recorded by the 1981 counter within the same distance from shore. Counts from Sectors 1 through 4 of each counter were analyzed using the chi-square contingency table (Table 5), resulting in a calculated X^2 value of 31,916. Since the calculated value greatly exceeded the tabled value (X^2, alpha = 0.05, 3 df = 7.81), the null hypothesis that the proportion of targets by counting sector was independent of counter type was rejected. These data suggest that some proportion of the escapement reacted to the presence of the structure by moving offshore and crossing the substrate in deeper water.

The extent of difference in distribution of targets recorded by the two counters may have been masked by the fixed hit criteria used in processing signals with the 1981 counter (Table 6). Throughout the enumeration period, there was a tendency for the 1981 counter to undercount fish in the middle sectors (primarily Sectors 4-9), although oscilloscope observations indicated that returning echoes were of sufficient magnitude and duration to count (Table 7). In order to provide the most accurate estimate of escapement, the pulse repetition rate of the counter was set so that fish that undercounted in the middle sectors were compensated for by overcounting in other sectors.

Table 6 shows the hit criteria for the two counters. The fixed criteria of the 1981 counter follow the theoretical pattern of increasing hits with increasing beam width. The hit criteria selected for the 1984 counter were adjusted to accurately reflect fish passage within each sector, although there were so few fish passing outside of sector 6 that the accuracy of the hit criteria in those sectors was not known. If one examines the characteristics of the beam as deployed in this situation, and the assumed bottom orientation of salmon as they pass through the beam, some feeling for the accuracy of the theoretical and actual hit criteria can be gained.

The theoretical hit criteria assumes that the average fish passes through the axis of the beam, and because the beam increases in size with distance, fish moving through at a constant speed will remain in the beam longer with distance. Therefore, to avoid multiple counts for a single fish, the hit criteria should also increase with distance. If, however, the fish does not pass through the axis of the beam, the hit criteria is dependent on how long the fish was in the beam, which is a function of the point of entry to and exit from the beam (cord length). Assuming that the average fish is closely oriented to the bottom, then the cord length of fish passage through the beam will be equal to or less than the maximum (passage through the axis of the beam). If, as in the case of the Bendix counters, the fish passes through the beam nearshore, it will pass through the axis since the beamwidth is approximately 4 inches and a sockeye salmon is typically greater than 4 inches in depth. If, however, the fish passes through the beam at it's maximum effective width (Sectors 6 and 12 of the 1981 counter) of approximately 2 ft, then it will not pass through the axis, and it's cord length approaches that of a fish entering the beam nearshore. Therefore, each fish is in the beam for essentially the same amount of time, and the hit criteria should be essentially equal with distance. Assuming that the 1984 counter correctly reflected processing criteria, it is apparent that there is negligible difference in hit criteria with distance from shore despite change in beamwidth. If this is true, then the result would be a tendency to undercount in the middle sectors of the 1981 counter.

The above discussion suggests that the presence of the artificial substrate altered fish behavior, and that the fixed hit criteria resulted in inaccurate distribution information; however, there are other potential explanations for the differences between the two counters. It is possible that there were natural changes in the migratory path of fish past the respective counters, or that the presence of the 1981 counter substrate and weir affected the distribution of fish upstream. The effects of current on fish passage past the two counters is also unknown.

It is, however, apparent that the fixed criteria is inappropriate for assessing fish distribution. Regardless of the factors which influence migratory behavior and distribution, the variable hit criteria feature present on the 1984 counter, and adequate visual (oscilloscope) observation allow more accurate assessment of distribution of fish past the beam.

In summary, the 1984 counter offers several advantages over the 1981 counter for the enumeration of sockeye salmon in the Kenai River. In-season maintenance of equipment is reduced without an 18-m substrate to clean and move. Calibration time is also reduced because fish behavior is not altered by the presence of the substrate. Major diurnal shifts in upstream swimming speed recorded for fish crossing the substrate are substantially reduced, as are adjustments in pulse repetition rate to account for fish distribution in the middle sectors. Post-season data analysis is also more accurate in terms of the distribution of upstream migrating fish.

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Table 1. Sonar counts and calibration data collected with the 1981 model Bendix Corp. side-scanning sonar counter on the north bank of the Kenai River, 1986.

			Count by Sector													Calibration Data				
																Time		Count		Percent
Month	Day	Hour	1	2	3	4	5	6	7	8	9	10	11	12	Total	Start	End	Sonar	Scope	Agreement
7	21	1400	13	126	200	132	14	2	12	20	19	40	30	61	669	1321	1328	43	55	78%
																1329	1337	64	67	96%
		1500	10	12	59	83	24	5	12	16	25	44	58	62	410	1416	1429	67	80	84%
																1430	1440	66	79	84%
		1700	63	862	736	176	17	2	2	14	12	13	12	40	1949	1632	1637	105	82	128%
																1637	1640	76	60	127%
																1640	1644	84	73	115%
																1644	1647	42	57	74%
		2100	536	1819	336	86	1			2	5	21	58	283	3147	2044	2048	123	103	119%
																2050	2055	73	103	71%
																2055	2102	80	100	80%
		2200	134	888	312	75	3		5	4	1	7	13	70	1512	2103	2107	137	104	132%
																2108	2114	112	101	111%
																2115	2118	102	97	105%
		2400	54	928	343	153	12	3	15	10	11	21	36	45	1631	2316	2323	228	210	109%
																2342	2352	61	58	70%

- Continued -

Table 1. (p. 2 of 8)

			Count by Sector													Calibration Data				
																Time		Count		Percent
Month	Day	Hour	1	2	3	4	5	6	7	8	9	10	11	12	Total	Start	End	Sonar	Scope	Agreement
7	22	100	177	533	305	116	10	4	2	5	3	7	23	53	1238	0008	0013	113	103	110%
																0013	0016	25	25	100%
		1600	20	160	76	37			1	3	2	4	12	49	364	1528	1535	32	48	67%
																1538	1542	23	27	85%
																1544	1551	16	18	89%
																1552	1557	53	52	102%
		1800	21	398	179	72	2				1	3	5	14	695	1745	1750	72	57	126%
																1750	1755	41	38	108%
		2400	43	449	152	86	8	2	3	4	10	13	19	68	857	2320	2326	104	100	104%
																2329	2335	118	110	107%
																2355	0005	113	95	119%
7	23	100	52	327	106	49	1		3	4		6	29	17	594	0010	0015	104	108	96%
		2200	34	1164	341	29					1	4	5	14	1592	2115	2121	106	108	98%
																2125	2143	308	239	129%
																2145	2149	122	100	122%
																2150	2154	120	99	121%
																2155	2158	137	127	108%
		2300	30	1082	335	31	2			2	1	1	16	14	1514	2201	2212	254	222	114%
																2214	2222	152	151	101%
		2400	17	577	211	56	2	0	2	5	5	8	27	14	924	2300	2306	130	108	120%

- Continued -

Table 1. (p. 3 of 8)

Month	Day	Hour	Count by Sector 1	2	3	4	5	6	7	8	9	10	11	12	Total	Calibration Data: Time Start	Time End	Count Sonar	Count Scope	Percent Agreement
7	24	2100	25	1203	713	155			1		1	20	3	7	2128	2022	2027	98	102	96%
		2200	26	1776	834	103						37		12	2788	2107	2112	112	99	113%
																2114	2118	141	125	113%
																2119	2124	162	142	114%
																2125	2128	122	119	103%
		2300	39	2087	702	70	1	1		1	1	70	16	30	3018	2236	2239	175	150	117%
																2242	2246	153	126	121%
																2248	2257	188	176	107%
		2400	8	883	488	62	2	0	2	1	2	22	4	18	1492	2336	2338	144	141	102%
7	25	1600	32	1123	452	38	2		1			3	6	10	1667	1535	1539	51	41	124%
																1539	1541	37	28	132%
																1542	1548	99	100	99%
		2100	58	1743	543	73				2		4	8	12	2443	2036	2038	120	102	118%
																2039	2046	80	105	76%
		2200	25	1373	667	160	5				2	2	3	4	2241	2116	2119	157	149	105%
																2122	2127	118	122	97%
		2400	66	1384	581	147	3				1	7	15	8	2212	2316	2320	176	149	118%
																2325	2330	117	89	131%
																2332	2342	210	170	124%

- Continued -

Table 1. (p. 4 of 8)

Month	Day	Hour	Count by Sector 1	2	3	4	5	6	7	8	9	10	11	12	Total	Calibration Data: Time Start	Time End	Count Sonar	Count Scope	Percent Agreement
7	26	1100	134	739	436	201	6	1	1		4	18	12	24	1576	1018	1020	74	55	135%
																1021	1026	82	100	82%
																1027	1031	153	100	153%
7	26	1100														1031	1032	30	25	120%
																1033	1037	80	100	80%
																1038	1040	41	50	82%
																1040	1042	60	50	120%
7	26	1200	7	210	418	236	26	5	5	6	4	29	17	15	978	1106	1113	27	50	54%
																1114	1116	29	50	58%
																1117	1123	74	100	74%
																1124	1129	113	100	113%
																1130	1134	121	100	121%
																1145	1152	128	157	82%
																1153	1201	48	50	96%
		1500	18	36	275	505	52	12	9	16	8	21	20	15	987	1400	1404	14	33	42%
																1405	1411	42	60	70%
																1411	1417	46	52	88%
																1417	1723	94	100	94%
																1424	1434	102	130	78%
																1434	1442	82	72	114%
																1442	1449	89	100	89%

- Continued -

Table 1. (p. 5 of 8)

Month	Day	Hour	Count by Sector 1	2	3	4	5	6	7	8	9	10	11	12	Total	Calibration Data: Time Start	Time End	Count Sonar	Count Scope	Percent Agreement
		2200	6	568	1550	994	26		1	0	0	0	3	7	3155	2116	2119	99	108	92%
		2300	17	1001	1962	827	6		1		1	1	10	3	3829	2224	2227	130	102	127%
																2228	2231	164	143	115%
																2231	2234	145	139	104%
																2238	2241	189	175	108%
																2243	2246	146	167	87%
		2400	20	1141	1377	395	1	0	1		1	2	6	3	2947	2303	2307	150	129	116%
																2308	2312	130	158	82%
																2313	2316	88	82	107%
																2317	2319	105	108	97%
																2339	2344	194	179	108%
																2345	2349	180	167	108%
																2350	2354	114	127	90%
7	27	2000	13	222	869	441	11	1	2	3	1	4	3	4	1574	1911	1915	132	109	121%
																1916	1919	117	100	117%
7	27	2000														1920	1923	114	102	112%

- Continued -

Table 1. (p. 6 of 8)

Month	Day	Hour	Count by Sector 1	2	3	4	5	6	7	8	9	10	11	12	Total	Calibration Data: Time Start	Time End	Count Sonar	Count Scope	Percent Agreement
		2100	5	253	974	474	13	2	1		5	3	1		1731	2015	2018	65	95	68%
																2019	2025	123	126	98%
		2400	51	760	1453	697	31	14	12	12	12	16	28	49	3135	2300	2303	112	89	126%
																2327	2329	170	111	153%
																2330	2334	109	94	116%
																2335	2339	129	229	56%
																2341	2347	109	110	99%
																2358	0003	136	124	110%
7	28	2200	2	98	460	493	27	9	8	3	4	16	21	12	1153	2101	2111	146	126	116%
																2114	2138	214	190	113%
																2130	2035	120	105	114%
																2036	2041	143	120	119%
																2042	2046	107	105	102%
		2300	7	120	622	532	19	5	3	6		2	4	12	1332	2218	2225	120	131	92%
																2247	2251	109	103	106%
		2400	3	190	619	504	17	4	2	5	3	3	3	12	1365	2309	2313	121	103	117%
																2315	2320	169	156	108%
																2321	2327	130	125	104%
																2332	2339	130	138	94%
																2350	2355	109	88	124%
																2359	0005	83	104	80%

- Continued -

Table 1. (p. 7 of 8)

			Count by Sector													Calibration Data				
																Time		Count		Percent
Month	Day	Hour	1	2	3	4	5	6	7	8	9	10	11	12	Total	Start	End	Sonar	Scope	Agreement
7	29	2200		4	55	242	23	11	4	3	10	33	42	31	458	2150	2157	47	56	84%
																2130	2140	65	64	102%
																2144	2206	117	134	87%
7	30	1200	1		3	22	8	2	6	1	1	32	36	36	148	1116	1125	14	9	156%
																1125	1135	5	5	100%
		2200	15	145	719	679	7	3		1		13	5	11	1598	2110	2113	91	69	132%
																2114	2118	100	75	133%
7	30	2200														2119	2122	52	53	98%
																2146	2152	101	105	96%
																2153	2158	42	43	98%
		2300	6	200	689	340	4		1		1	6	6	8	1261	2208	2213	85	84	101%
																2225	2234	141	136	104%
																2249	2300	157	110	143%
7	30	2400	24	313	645	274	2	1	2	2		15	10	15	1303	2301	2310	107	107	100%
																2312	2319	118	124	95%
																2350	0002	125	89	140%

- Continued -

Table 1. (p. 8 of 8)

			Count by Sector													Calibration Data				
																Time		Count		Percent
Month	Day	Hour	1	2	3	4	5	6	7	8	9	10	11	12	Total	Start	End	Sonar	Scope	Agreement
7	31	2200	4	12	103	465	30	11	14	10	7	53	28	42	779	2117	2122	41	60	68%
																2122	2125	17	20	85%
		Total	1820	26917	21912	10326	438	124	162	193	201	664	697	1252	64394					
		%	2.8	41.8	34.0	16.0	0.7	0.2	0.3	0.3	0.3	1.0	1.1	1.9	100.0					

Table 2. Sonar counts and calibration data collected with the 1984 model Bendix Corp. side-scanning sonar counter on the north bank of the Kenai River, 1986.

			Count by sector																	Calibration data				
																				Time		Count		Percent
Month	Day	Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total	Start	End	Sonar	Scope	Agreement
7	21	1400	75	565	40		2	9	4				1						696	1308	1314	64	58	110%
																				1315	1320	46	38	121%
																				1321	1325	127	102	125%
																				1330	1335	36	26	138%
																				1337	1340	100	111	90%
																				1345	1400	46	47	98%
		1500	8	202	85		9	17	1	7	11	4	6						350	1450	1502	72	69	104%
		1700	337	1034	60								1						1432	1608	1613	335	309	108%
																				1621	1628	347	319	109%
																				1629	1632	58	56	104%
																				1640	1645	103	100	103%
		2100	1006	1626	56	1	6	4	1	1	2	4	5						2712	2037	2039	89	93	96%
		2200	505	1148	66		10	1			5	4	4		1	14			1758	2120	2124	129	112	115%
																				2125	2129	110	99	111%
																				2129	2134	114	106	108%
		2400	581	628	75		6	14			2	4	9						1319	2311	2317	101	102	99%

- Continued -

Table 2. (p. 2 of 5)

			Count by sector																	Calibration data				
																				Time		Count		Percent
Month	Day	Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total	Start	End	Sonar	Scope	Agreement
7	22	100	960	508	21		12	24			2	4	1						1532	2400	2406	148	133	111%
		1600	25	296	84		5	2	1		5	2	1						421	1509	1513	26	25	104%
																				1520	1530	93	100	93%
		1800	77	458	109	1		2				5							652	1657	1706	93	103	90%
																				1710	1716	109	124	88%
																				1720	1732	92	107	86%
																				1738	1745	121	115	105%
		2400	311	587	49						3	2							952	2322	2338	325	324	100%
																				2346	2353	156	135	116%
7	23	100	326	351	20														697	2355	0017	272	292	93%
		2200	203	1276	134	1			3	1	1	2							1621	2117	2121	105	101	104%
																				2151	2153	111	111	100%
		2300	323	1461	106	2	3				1	7							1903	2234	2238	205	174	118%
7	23	2300																		2241	2250	221	213	104%
		2400	239	915	58	1		4	1	1	7	5							1231	2340	2351	191	144	133%
																				2354	0003	90	84	107%

- Continued -

Table 2. (p. 3 of 5)

			Count by sector																	Calibration data				
																				Time		Count		Percent
Month	Day	Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total	Start	End	Sonar	Scope	Agreement
7	24	2100	188	1949	189	1		1				1							2329	2033	2036	100	123	81%
																				2039	2044	114	116	98%
																				2049	2053	123	130	95%
		2200	351	2412	139			1				2							2905	2130	2133	103	113	91%
																				2134	2136	116	112	104%
																				2137	2139	123	110	112%
																				2140	2143	75	77	97%
		2300	339	2592	208	1					1	1							3142	2228	2231	122	130	94%
																				2232	2234	108	105	103%
		2400	352	1571	181	1		1				8							2114	2323	2228	183	182	101%
7	25	1600	39	996	175							1							1211	1510	1518	118	104	113%
																				1519	1523	72	60	120%
																				1527	1532	49	45	109%
		2100	212	2152	263	3	2				1	2	2						2637	2026	2028	138	145	95%
																				2031	2033	98	98	100%
																				2033	2037	191	171	112%
		2200	206	2351	290	1	3	14		1	8	3							2877	2142	2146	148	144	103%
		2400	284	1707	191	1		4			2								2189	2301	2304	114	131	87%
																				2308	2314	122	117	104%
																				2350	2355	193	149	130%

- Continued -

Table 2. (p. 4 of 5)

			Count by sector																	Calibration data				
																				Time		Count		Percent
Month	Day	Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total	Start	End	Sonar	Scope	Agreement
7	26	1100	168	1296	85	3	4	4	5		1	3							1569	1030	1035	189	166	114%
																				1038	1042	151	145	104%
		1200	106	1424	158	4	3			2	4	1							1702	1104	1111	126	106	119%
																				1112	1117	176	141	125%
																				1118	1121	110	108	102%
																				1122	1124	132	125	106%
																				1130	1134	124	120	103%
7	26	1500	6	750	250		1				3	6	3						1019	1442	1448	108	111	97%
		2200	334	2382	133			1			1								2851	2106	2109	108	126	86%
																				2110	2014	132	127	104%
		2300	680	2480	75			6											3241	2218	2222	143	141	101%
																				2253	2256	151	154	98%
7	26	2400	811	2744	66	1		24											3646	2335	2339	201	190	106%
7	27	2000	38	1566	300		1				1	1	4						1911	1903	1909	119	114	104%
		2100	50	1943	329			2											2324	2008	2012	118	122	97%
		2400	307	2253	192	5	3	4											2764	2350	2354	119	113	105%
7	28	2200	8	777	253	2													1040	2149	2153	100	105	95%
		2300	15	993	273		1			1	1	1	7						1292	2205	2213	136	111	123%
		2400	26	1033	309	2	2	1	1										1374	2342	2348	106	103	103%

- Continued -

Table 2. (p. 5 of 5)

			Count by sector																	Calibration data				
																				Time		Count		Percent
Month	Day	Hour	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total	Start	End	Sonar	Scope	Agreement
7	29	2200		164	223	2	61			1	5	2							458	2102	2111	32	50	64%
																				2119	2132	61	72	85%
7	30	1200		14	36		1		1	2		1							55	1145	1200	20	20	100%
		2200	45	1516	253			16	1	1	3		1						1836	2125	2128	120	100	120%
																				2136	2140	122	105	116%
																				2141	2145	110	107	103%
		2300	50	1188	174			3	1	1			1						1418	2200	2205	109	105	104%
																				2239	2243	143	132	108%
																				2244	2252	153	149	103%
		2400	137	1162	61	1	1	9		1	1		1						1374	2322	2327	117	98	119%
																				2328	2338	135	127	106%
7	31	2200	4	429	220		3	2	1	3	1	4							667	2128	2135	60	58	103%
		Total	9734	50903	5995	42	149	182	35	39	90	100	69	24	27	42	30	32	67221					
		%	14.5	75.7	8.9	0.1	0.2	0.3	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.1	0.0	0.0	100.0					

Table 3. Results of a Wilcoxen's paired sample test using data collected with the 1981 and 1984 model Bendix Corp. side-scanning sonar counters on the north bank of the Kenai River, 1986.

Month	Day	Hour	Hour #	Count from 1981 model (X1j)	Count from 1984 model (X2j)	Diff (Dj) (X1j-X2j)	Percent Diff. (1-X1j/X2j)	Rank (Dj)	Negative signed rank	Positive signed rank
7	21	1400	1	669	696	-27	3.9%	5	5	
		1500	2	410	350	60	-17.1%	11		11
		1700	3	1949	1432	517	-36.1%	34		34
		2100	4	3147	2712	435	-16.0%	32		32
		2200	5	1512	1758	-246	14.0%	24	24	
		2400	6	1631	1319	312	-23.7%	28		28
7	22	0100	7	1238	1532	-294	19.2%	25	25	
		1600	8	364	421	-57	13.5%	10	10	
		1800	9	695	652	43	-6.6%	9		9
		2400	10	857	952	-95	10.0%	14	14	
7	23	0100	11	594	697	-103	14.8%	15	15	
		2200	12	1592	1621	-29	1.8%	6	6	
		2300	13	1514	1903	-389	20.4%	31	31	
		2400	14	924	1231	-307	24.9%	27	27	
7	24	2100	15	2128	2329	-201	8.6%	22	22	
		2200	16	2788	2905	-117	4.0%	18	18	
		2300	17	3018	3142	-124	3.9%	19	19	
		2400	18	1492	2114	-622	29.4%	37	37	
7	25	1600	19	1667	1211	456	-37.7%	33		33
		2100	20	2443	2637	-194	7.4%	21	21	
		2200	21	2241	2877	-636	22.1%	38	38	
		2400	22	2212	2189	23	-1.1%	4		4
7	26	1100	23	1576	1569	7	-0.4%	2		2
		1200	24	978	1702	-724	42.5%	40	40	
		1500	25	987	1019	-32	3.1%	7	7	
		2200	26	3155	2851	304	-10.7%	26		26
		2300	27	3829	3241	588	-18.1%	35		35
		2400	28	2947	3646	-699	19.2%	39	39	
7	27	2000	29	1574	1911	-337	17.6%	29	29	
		2100	30	1731	2324	-593	25.5%	36	36	
		2400	31	3135	2764	371	-13.4%	30		30
7	28	2200	32	1153	1040	113	-10.9%	17		17
		2300	33	1332	1292	40	-3.1%	8		8
		2400	34	1365	1374	-9	0.7%	3	3	
7	29	2200	35	458	458	0	0.0%	1		1

- Continued -

Table 3. (p. 2 of 2)

Month	Day	Hour	Hour #	Count from 1981 model (X1j)	Count from 1984 model (X2j)	Diff (Dj) (X1j-X2j)	Percent Diff. (1-X1j/X2j)	Rank (Dj)	Negative signed rank	Positive signed rank
7	30	1200	36	148	55	93	-169.1%	13		13
		2200	37	1598	1836	-238	13.0%	23	23	
		2300	38	1261	1418	-157	11.1%	20	20	
		2400	39	1303	1374	-71	5.2%	12	12	
7	31	2200	40	779	667	112	-16.8%	16		16
		Total		64394	67221	-2827	4.2%		521	299

n = 40
T = sum of ranks with less frequent sign = 299
m = number of ranks with less frequent sign = 16
T′ = m(n + 1) - T = 16(41) - 299 = 357
Tabled T value: T 0.05 (2), 40 df = 264

Table 4. Linear regression of counts recorded by the 1981 model and 1984 model Bendix Corp. side-scanning sonar counters in the Kenai River, 1986.

N = 40

Ê X	=	6.439E+04	Ê Y	=	6.722E+04
mean X	=	1.610E+03	mean Y	=	1.681E+03
Ê X^2	=	1.351E+08	Ê Y^2	=	1.442E+08
(Ê X)^2/n	=	1.037E+08	(Ê Y)^2/n	=	1.130E+08
Ê x^2	=	3.148E+07	Ê y^2	=	3.126E+07

Ê X*Y	=	1.376E+08
sX*sY/n	=	1.082E+08
Ê x*y	=	2.934E+07

Analysis of Regression

calc r^2	=	0.875		
calc r	=	0.935	Table r ($P < 0.05$) =	.310
b	=	0.932	Lower b =	0.816
			Upper b =	1.048
a	=	180.131	S(y.x(0)) =	105.155
			Lower a =	-32.283
			Upper a =	392.544

Analysis of Variance

Source	DF	SS	MS	Calc F stat	Table F stat
Total	40	1.442E+08			
Mean	1	1.130E+08			
Regress	1	2.734E+07	2.734E+07		
Error	38	3.915E+06	1.030E+05	265.404	4.10

Analysis of Slope

S(y.x)	=	320.968	$S(y.x)^2$	=	1.03E+05
S(b)	=	0.057	$S(b)^2$	=	0.003
S(ybar.x)	=	50.75			
df	=	38			
Calc t	=	16.291	Table t ($P < 0.05$) =		2.020

1981 Counter (X)	1984 Counter (Y)
669	696
410	350
1,949	1,432
3,147	2,712
1,512	1,758
1,631	1,319
1,238	1,532
364	421
695	652
857	952
594	697
1,592	1,621
1,514	1,903
924	1,231
2,128	2,329
2,788	2,905
3,018	3,142
1,492	2,114
1,667	1,211
2,443	2,637
2,241	2,877
2,212	2,189
1,576	1,569
978	1,702
987	1,019
3,155	2,851
3,829	3,241
2,947	3,646
1,574	1,911
1,731	2,324
3,135	2,764
1,153	1,040
1,332	1,292
1,365	1,374
458	458
148	55
1,598	1,836
1,261	1,418
1,303	1,374
779	667

Table 5. Chi-square analysis of change in sector distribution by counter type in the Kenai River, 1986.

		Sector				
		1	2	3	4	Total
1981 model counter						
	observed	1816	26909	21900	10310	60935
	expected	5515	37160	13319	4940	60935
	deviation	-3699	-10251	8581	5370	0.00
	chi-square	2481	2828	5528	5837	16673.62
1984 model counter						
	observed	9732	50899	5989	34	66654
	expected	6033	40648	14570	5404	66654
	deviation	3699	10251	-8581	-5370	0.00
	chi-square	2268	2585	5053	5336	15243.00
Total	chi-square					31916.62

Table 6. Proportion of fish recorded for concurrent time periods by the 1981 Bendix Corp. side-scanning sonar counter and an oscilloscope observer on the Kenai River, 1986.

		Proportion of counts by sector group							
		Oscilloscope				1981 counter			
Date	Time (min)	1-3	4-6	7-9	10-12	1-3	4-6	7-9	10-12
7/23	18	0.837	0.155	0.000	0.008	0.948	0.026	0.003	0.023
	11	0.941	0.050	0.005	0.005	0.961	0.004	0.000	0.035
	8	0.810	0.190	0.000	0.000	0.947	0.053	0.000	0.000
7/24	4	0.250	0.750	0.000	0.000	0.333	0.667	0.000	0.000
	5	0.500	0.333	0.167	0.000	0.429	0.286	0.143	0.143
7/28	10	0.119	0.690	0.079	0.111	0.215	0.591	0.047	0.148
	24	0.179	0.726	0.058	0.037	0.323	0.576	0.028	0.074
7/29	22	0.052	0.821	0.037	0.090	0.214	0.598	0.051	0.137
7/30	9	0.522	0.419	0.015	0.044	0.717	0.241	0.000	0.041

Table 7. Hit criteria and distance from shore for each of the linear counting sectors of the 1981 model and 1984 model Bendix Corp. side-scanning sonar counters used on the Kenai River, 1986

	Sector number															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Distance (m) from shore to end of sector (1978 counter)	3.8	5.3	6.8	8.3	9.8	11.3	12.8	14.3	15.8	17.3	18.8	20.3				
Distance (m) from shore to end of sector (1984 counter)	3.8	5.3	6.8	8.3	9.8	11.3	12.8	14.3	15.8	17.3	18.8	20.3	21.8	23.3	24.8	26.3
Hit criteria (1978 counter)	3	3	3	4	5	6	4	4	5	5	6	6				
Hit criteria (1984 counter)	6	6	5	5	5	5	6	6	5	5	5	6	6	6	7	7

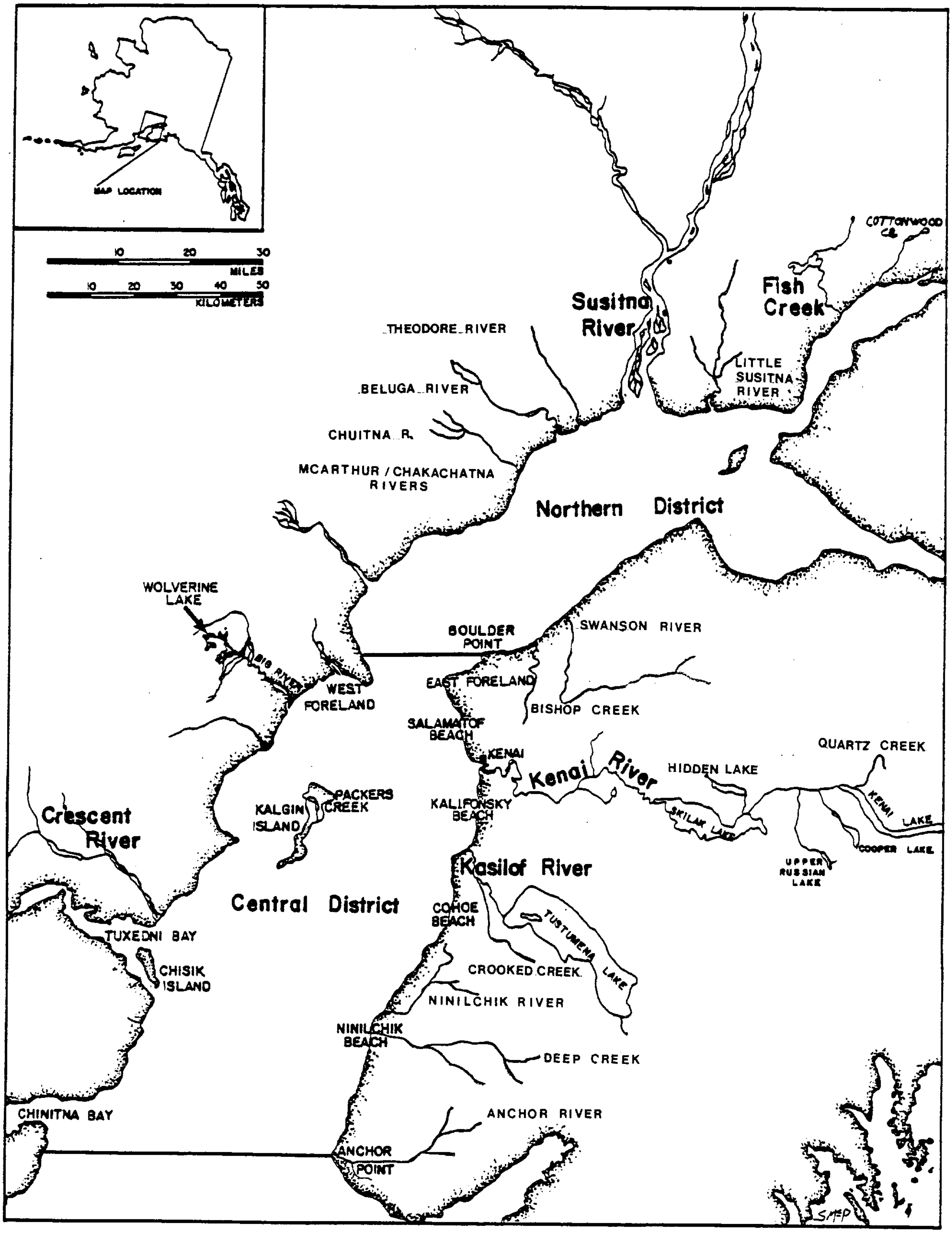

Figure 1. Major salmon spawning drainages of Upper Cook Inlet, Alaska.

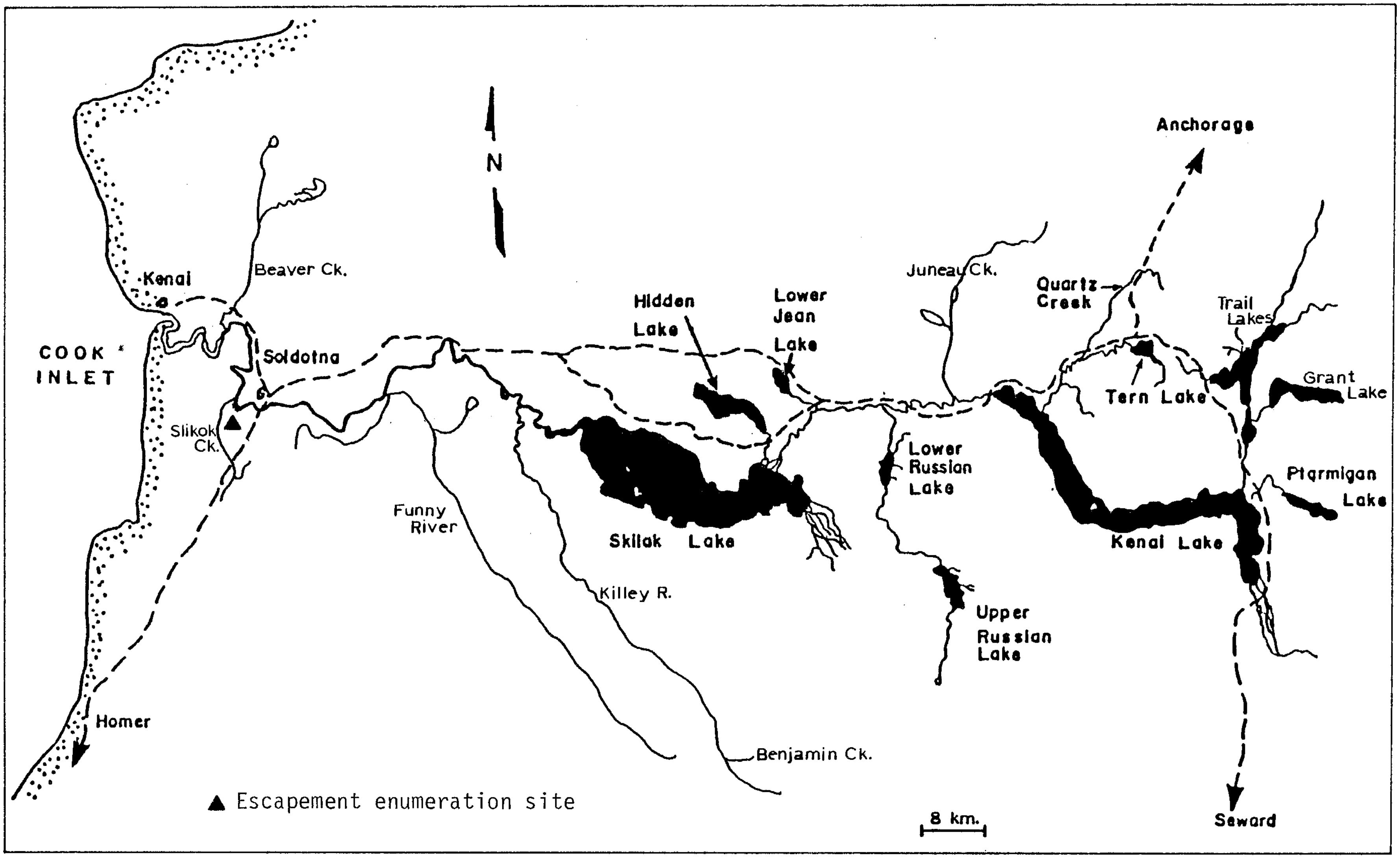

Figure 2. Kenai River drainage and major sockeye salmon rearing lakes.

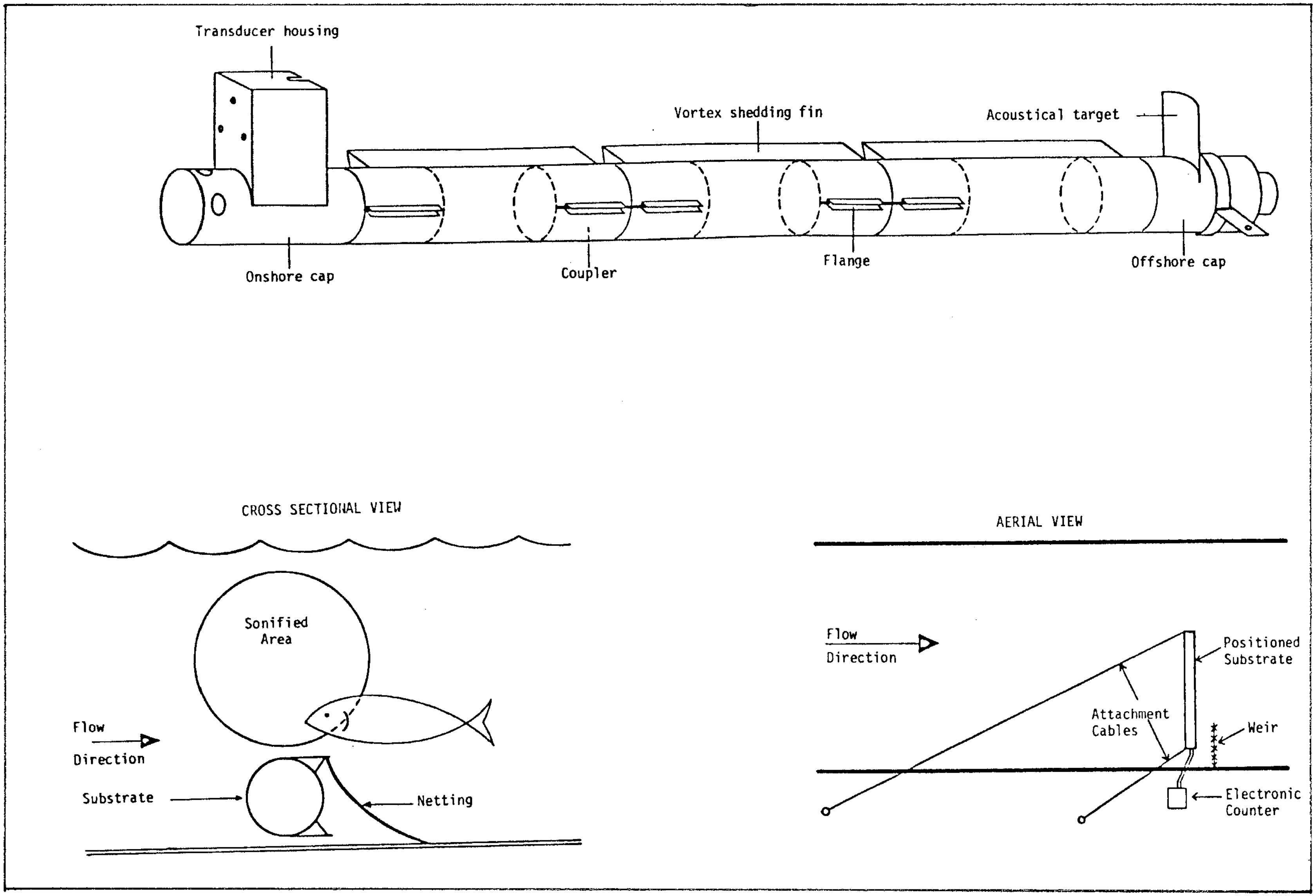

Figure 3. Side-scanning sonar system used to count salmon in Upper Cook Inlet, Alaska.

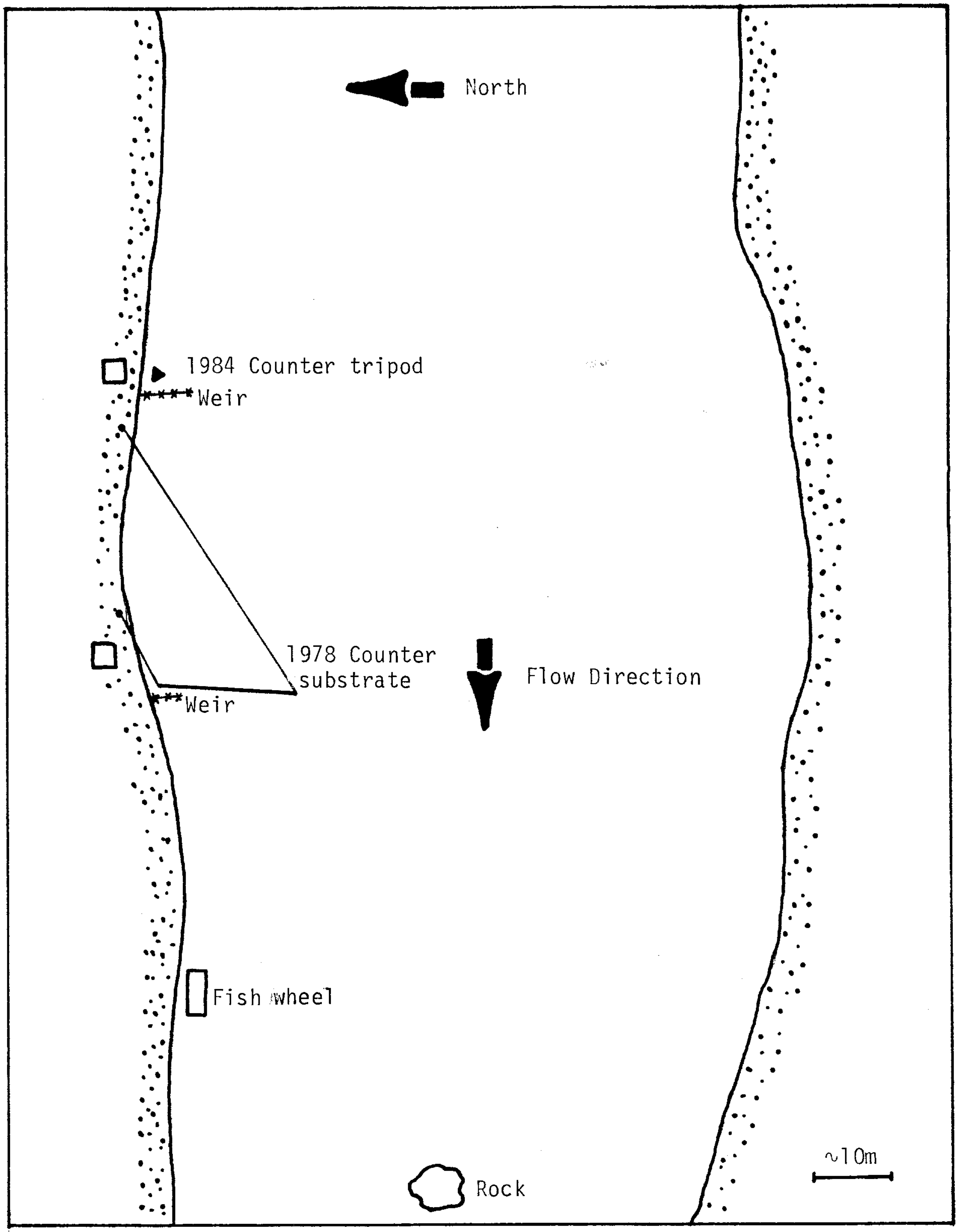

Figure 4. Approximate location of sampling equipment on the north bank of the Kenai River, 1986.

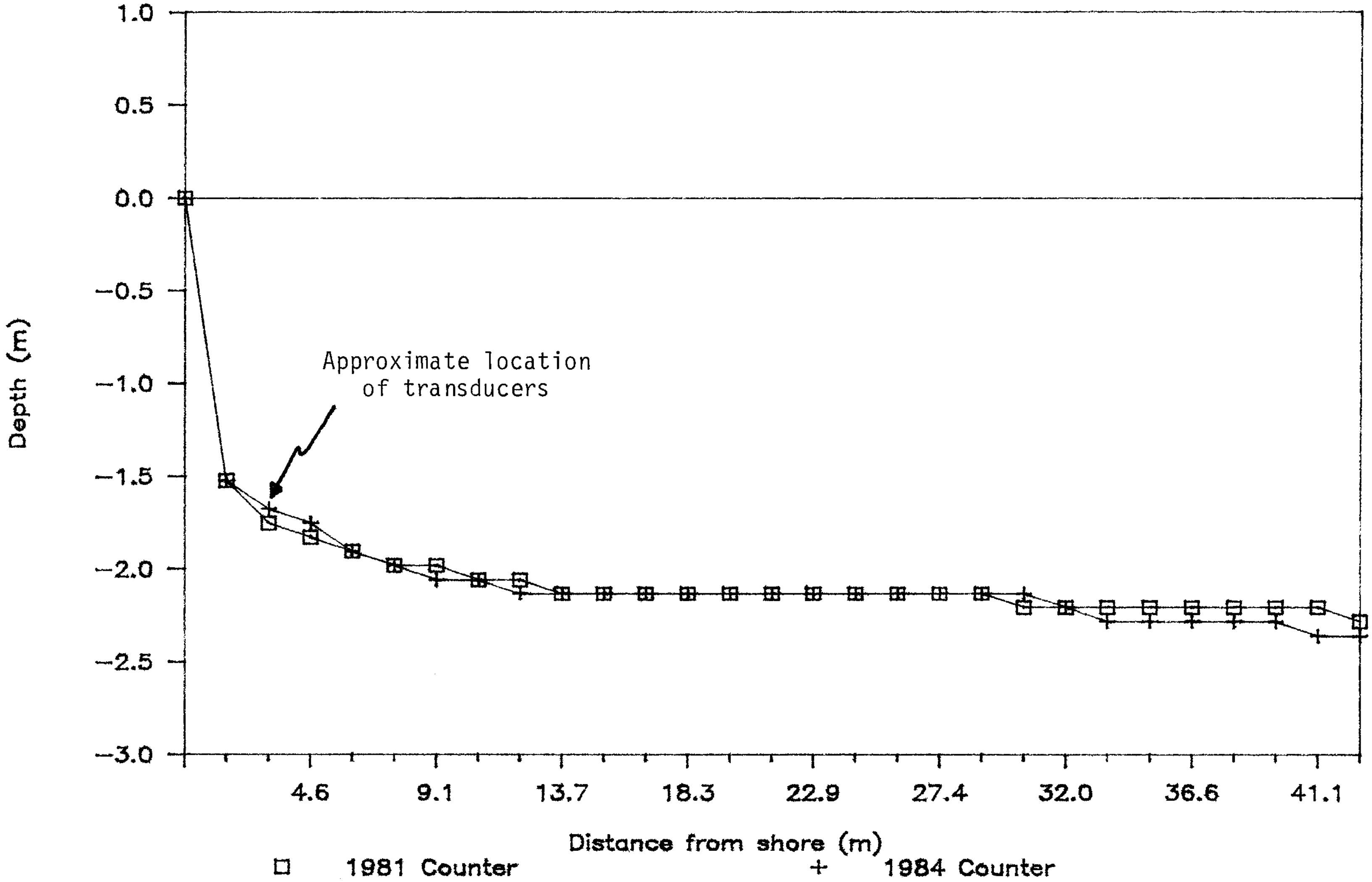

Figure 5. Bottom profiles measured at the locations of deployment of the 1981 and 1984 model Bendix Corp. side-scanning sonar counters on the north bank of the Kenai River, 1986.

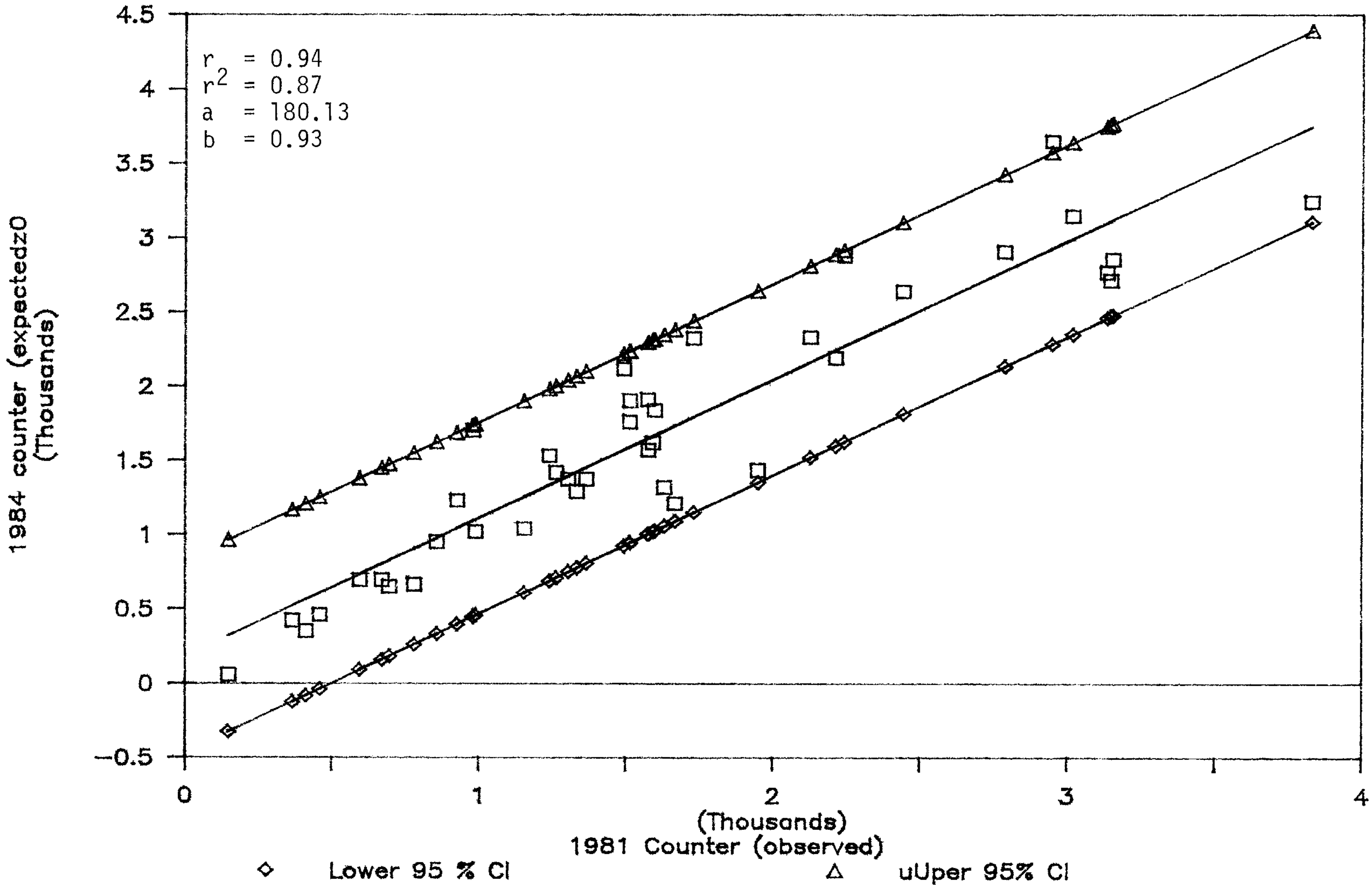

Figure 6. Linear regression analysis of paired hourly data collected with the 1981 and 1984 model Bendix Corp. side-scanning sonar counters in the Kenai River, 1986.

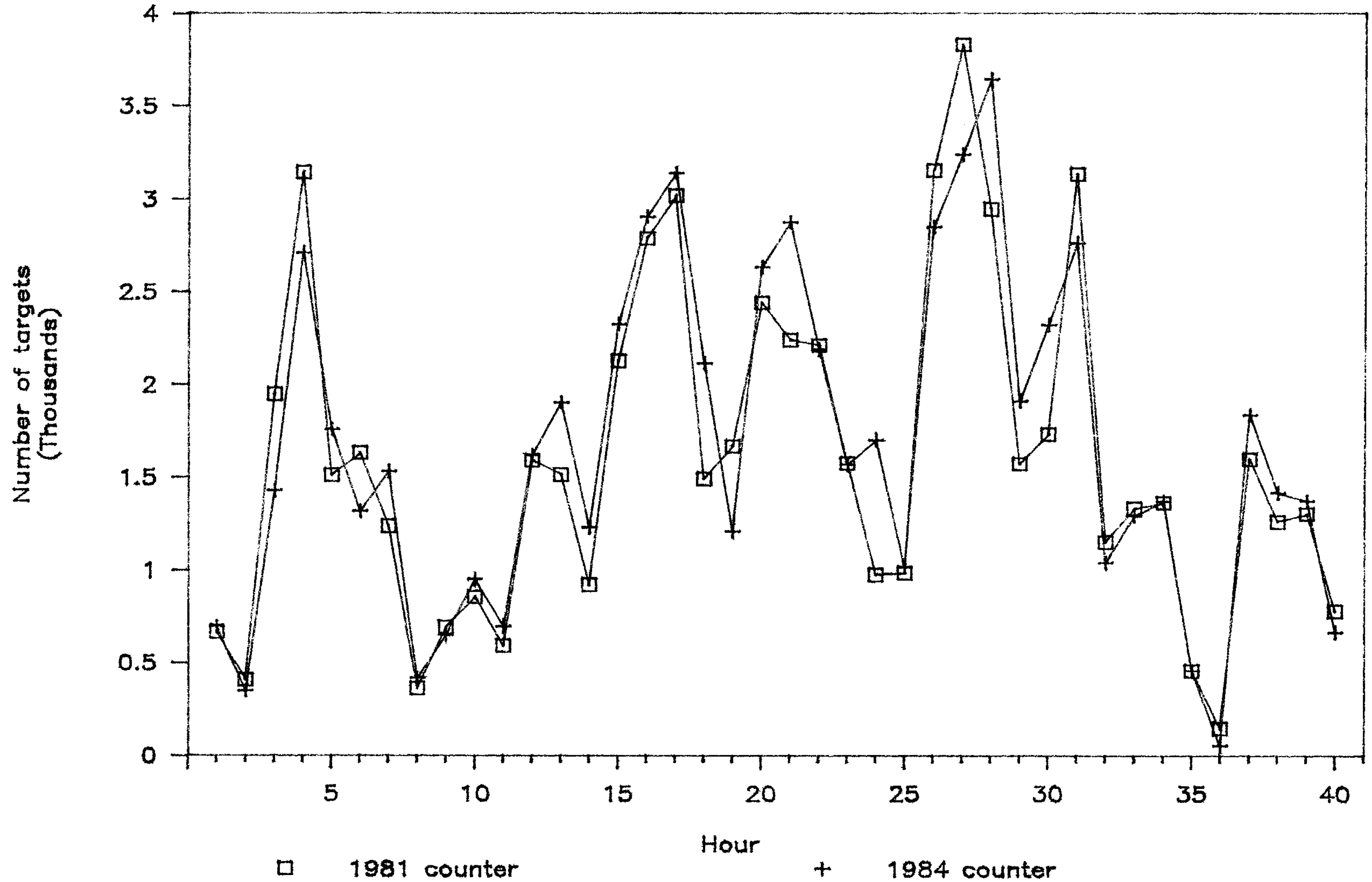

Figure 7. Paired hourly counts recorded by the 1981 and 1984 model Bendix Corp. side-scanning sonar counters in the Kenai River, 1986.

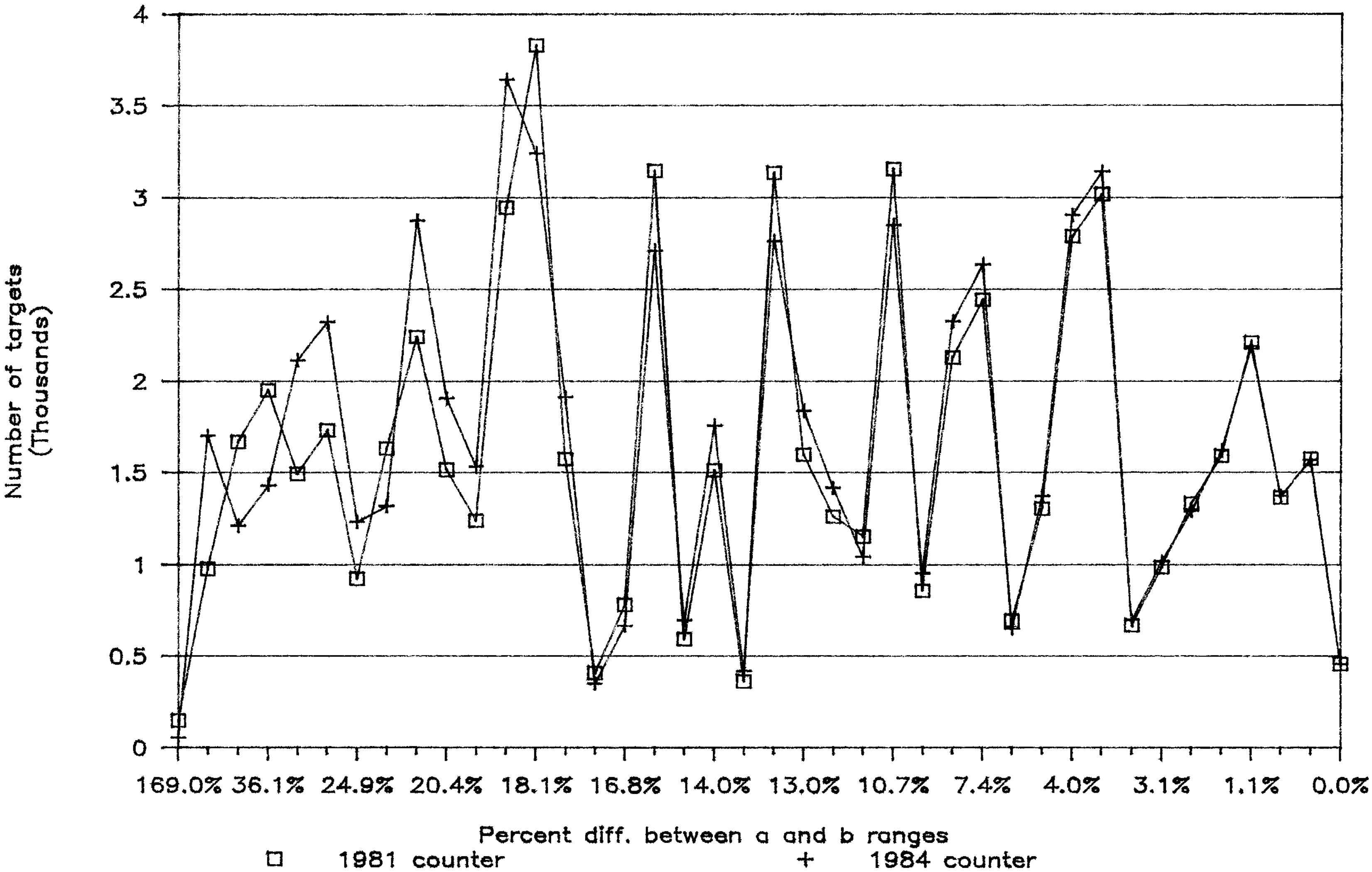

Figure 8. Differences in paired hourly counts at varied target density levels recorded by the 1981 and 1984 model Bendix Corp. side-scanning sonar counters in the Kenai River, 1986.

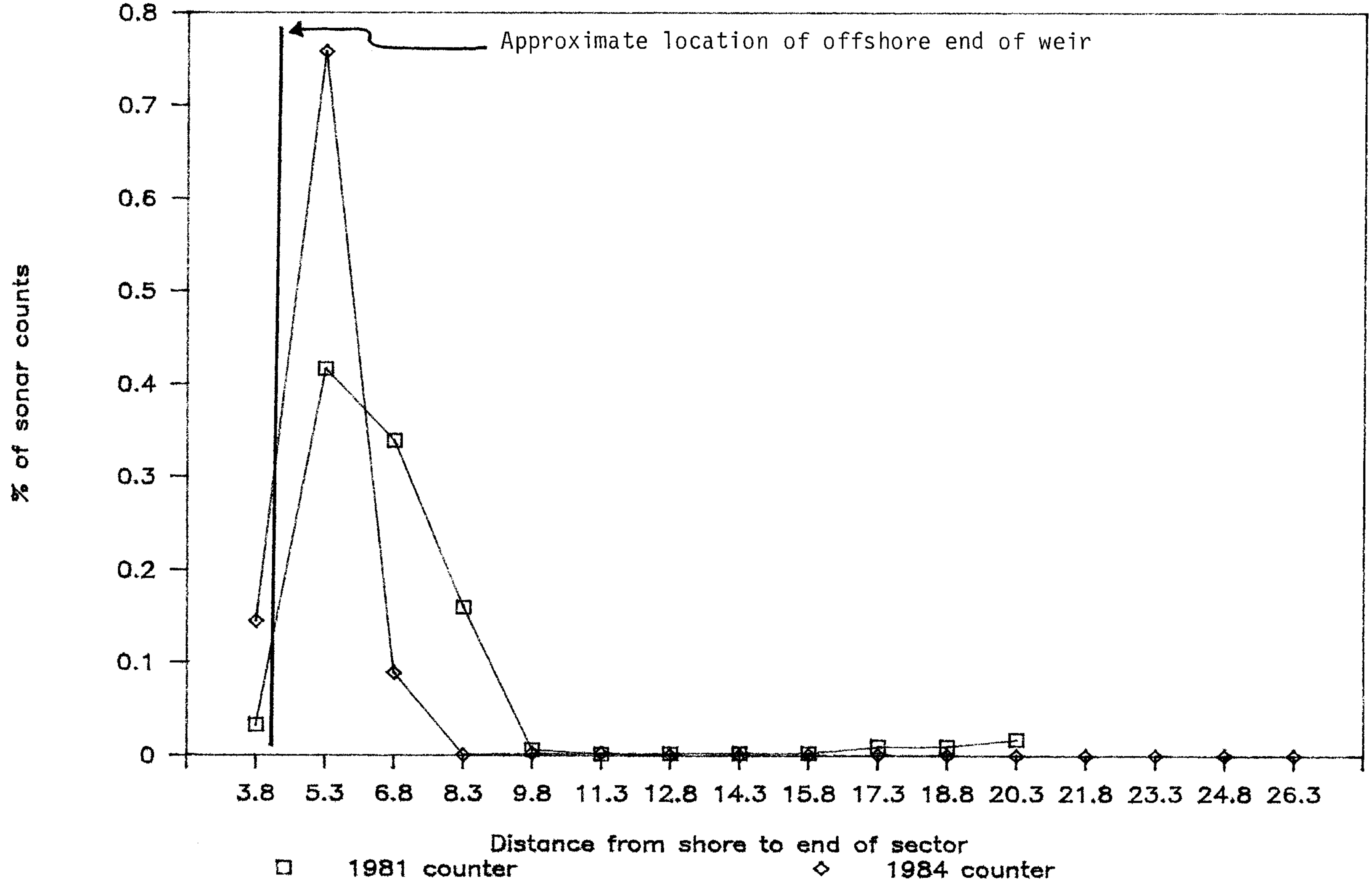

Figure 9. Distribution from shore of fish targets recorded by the 1981 and 1984 model Bendix Corp. side-scanning sonar counters in the Kenai River, 1986.